Self-Assembly and Self-Repair of Structures with Stability and Resource Constraints

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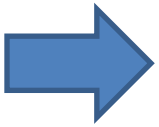
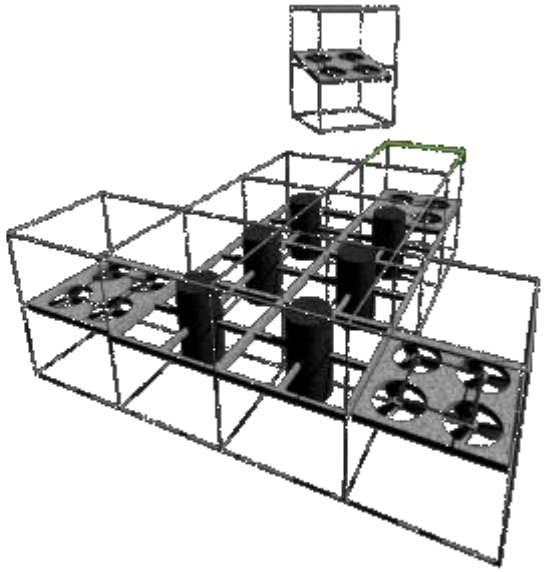
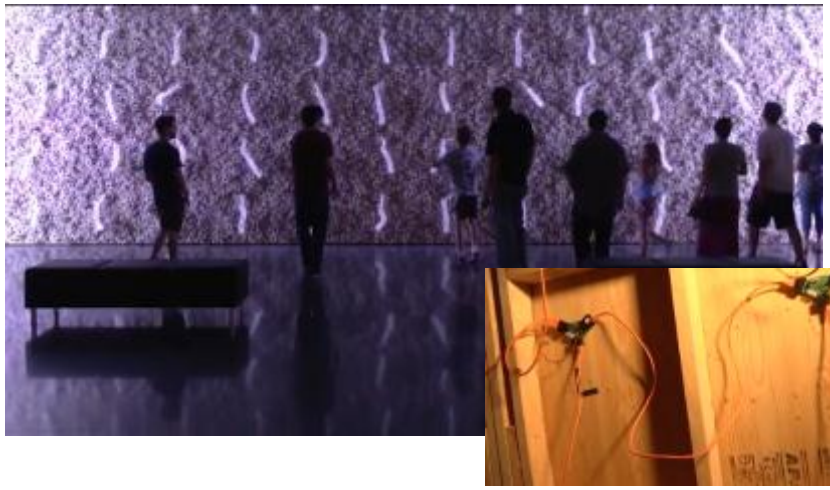
Vision





- Self-Assembly
- Self-Reconfiguration
- Self-Repair

Computational Materials



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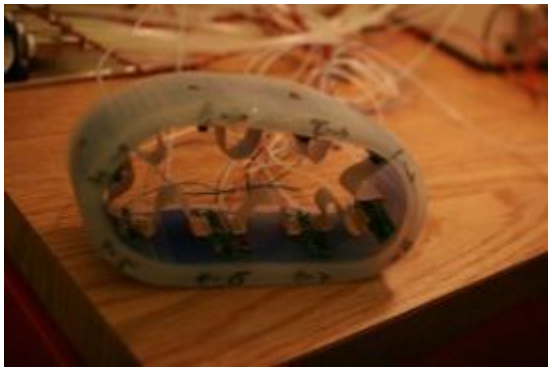

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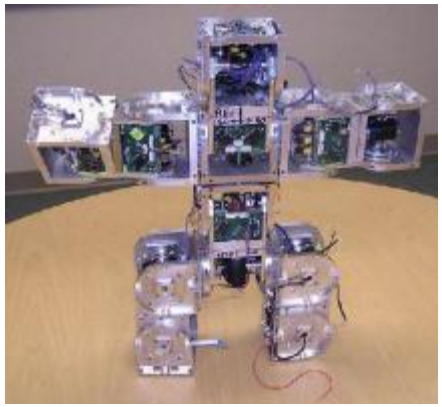
Challenges

- How to maintain *stability* during self-assembly in air?
- How to limit sensing, actuation and computation *resources*?
- How to *self-repair*?

Distributed Flight Array, Raffael d'Andrea, ETH



Superbot, Wei Min-Shen, USC

3 year grant, start April 1st, 2012

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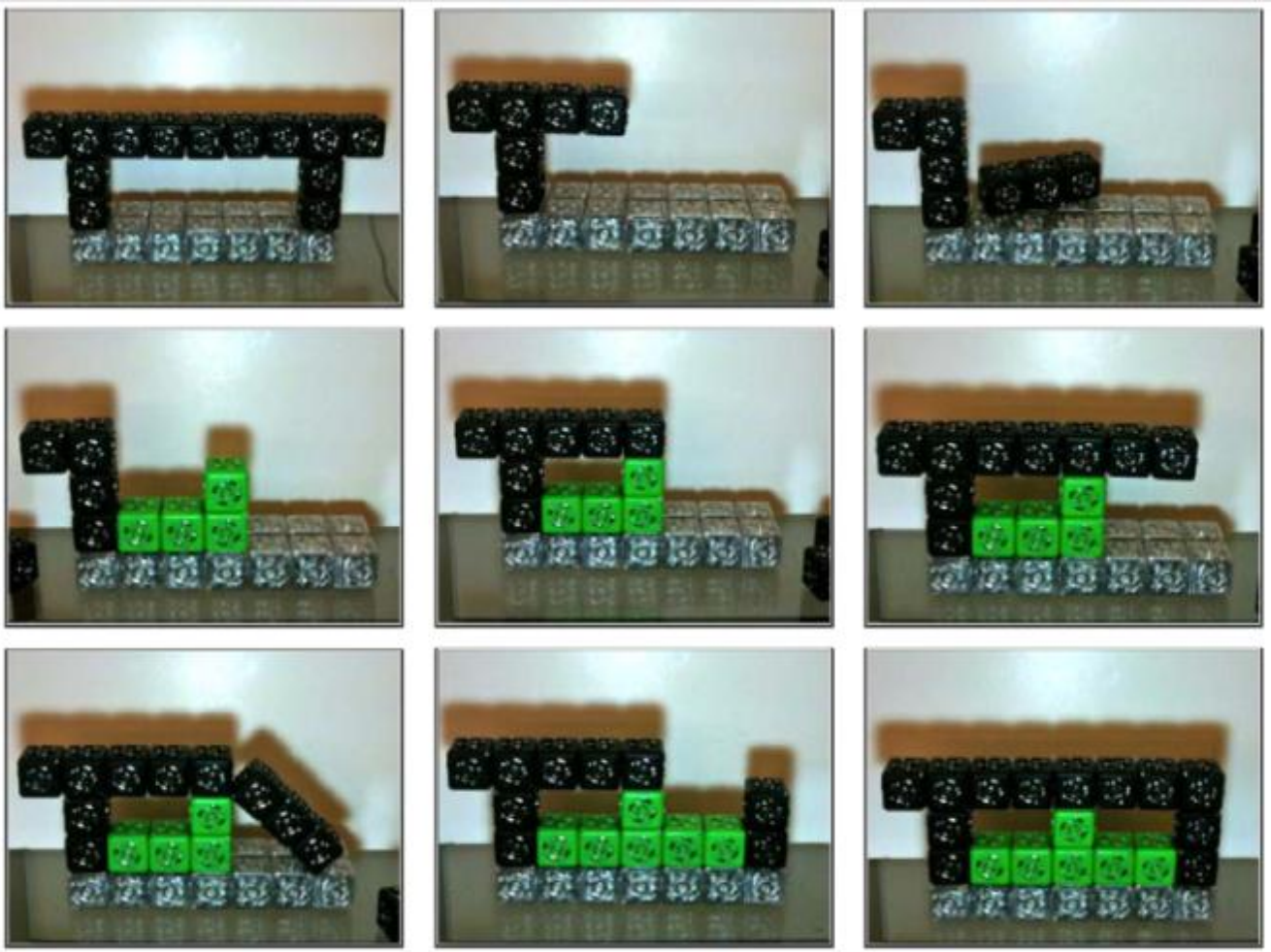
1. Stability

- Which *path* to choose to reach a desired configuration?
  - Basic physics
  - Wind, turbulences, vibrations, etc.
  - Sensor/Actuator limitations
- Adding restraints?

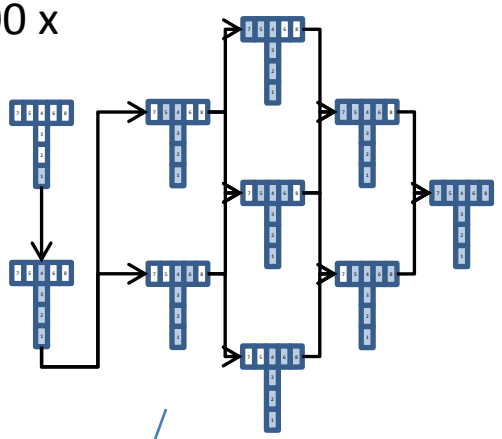
Example



Approach

- Combination of
  - Discrete search
  - Dynamical Simulation
  - Full physics, realistic simulation

10000 x



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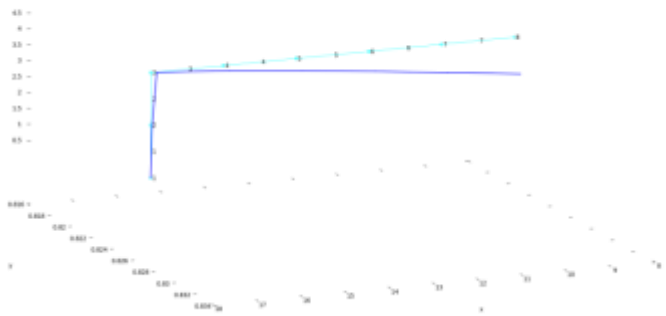

Frame3DD

10 x

Gazebo / ODE

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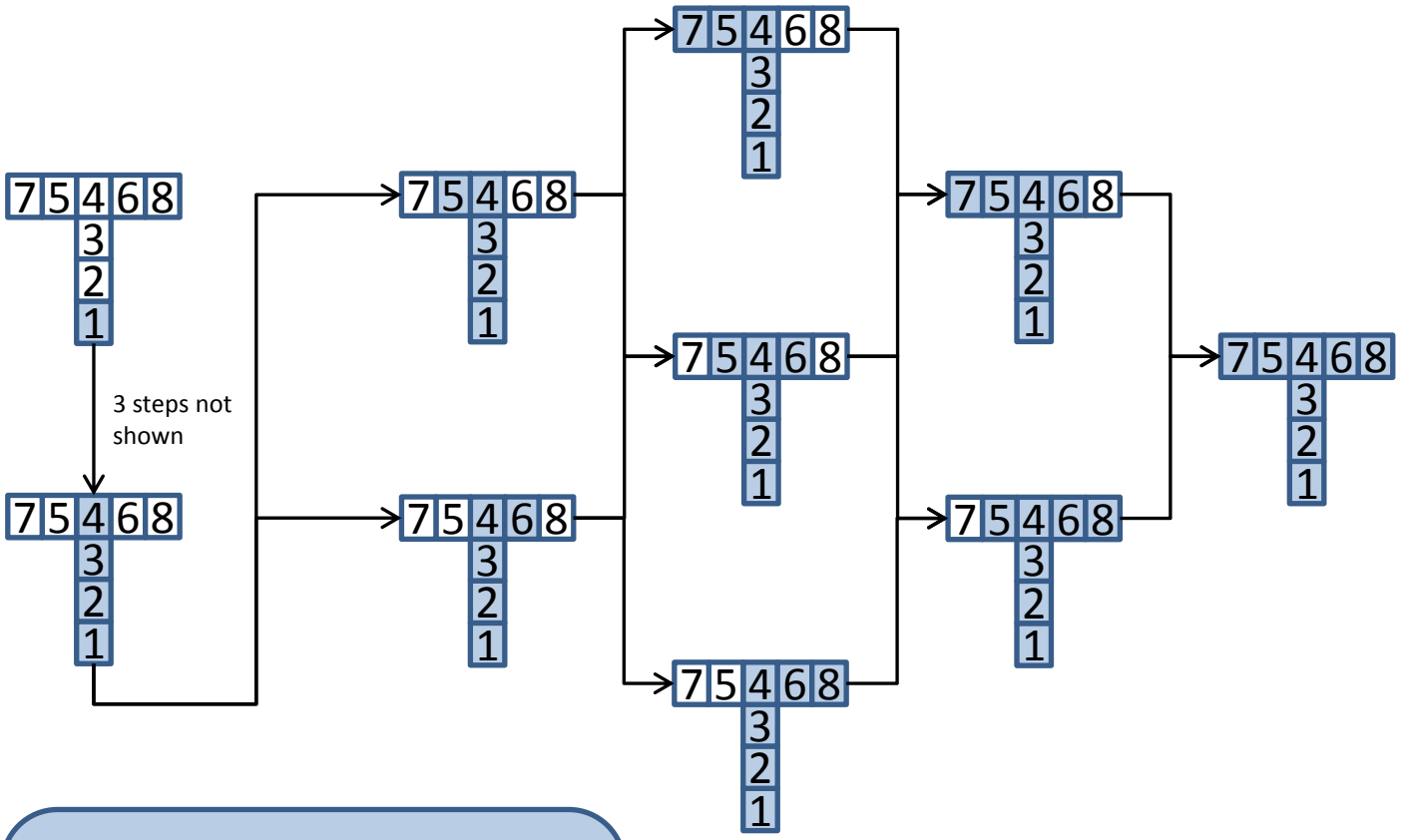
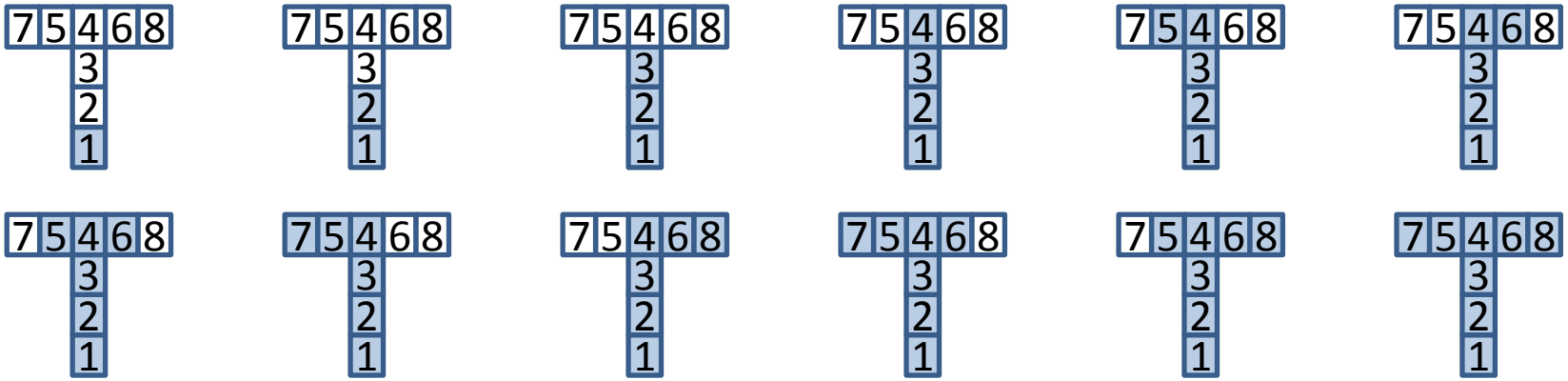
Tee Structure Assembly Graph



Valid Assembly Sequences:

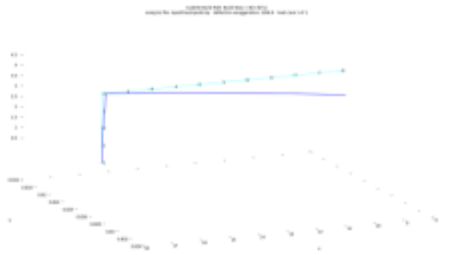
1,2,3,4,5,6,7,8
1,2,3,4,5,6,8,7
1,2,3,4,5,7,6,8
1,2,3,4,6,5,7,8
1,2,3,4,6,5,8,7
1,2,3,4,6,8,5,7

Tee Structure Assembly Graph Nodes



Analysis Sequences:

```
1
1,2
1,2,3
1,2,3,4
1,2,3,4,5
1,2,3,4,6
1,2,3,4,5,6
1,2,3,4,5,7
1,2,3,4,6,8
1,2,3,4,5,6,7
1,2,3,4,5,6,8
1,2,3,4,5,6,7,8
```



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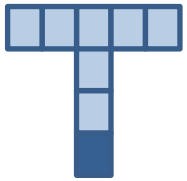
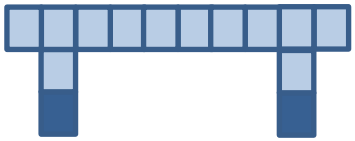
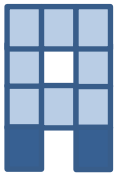
Other Structures



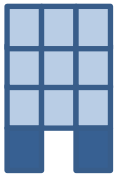
Tee



Bridge



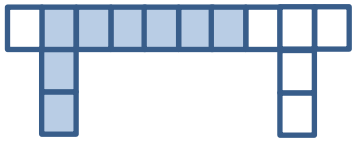
2D w/ Hole



2D w/ enclosed

Valid Assembly Paths	Graph Nodes to analyze
6	12
78	60
452	76
7985	243

Frame3DD FEA: Partial Bridge

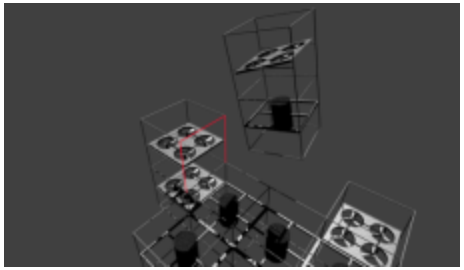


Analyzed Structure

Discussion: Stable Paths

- Fast heuristics needed for discrete search
  - Encode basic physics
  - Encode geometric constraints
- Identification of “critical” elements that need restraints
- Frame3DD -> arbitrary physics
  - From static assemblies to flying and swimming

7985?



2. Resources

- How to limit the number of building blocks with actuation, sensing, and computation?
  - Weight
  - Cost
- Approach: “Intelligent Scaffolds”

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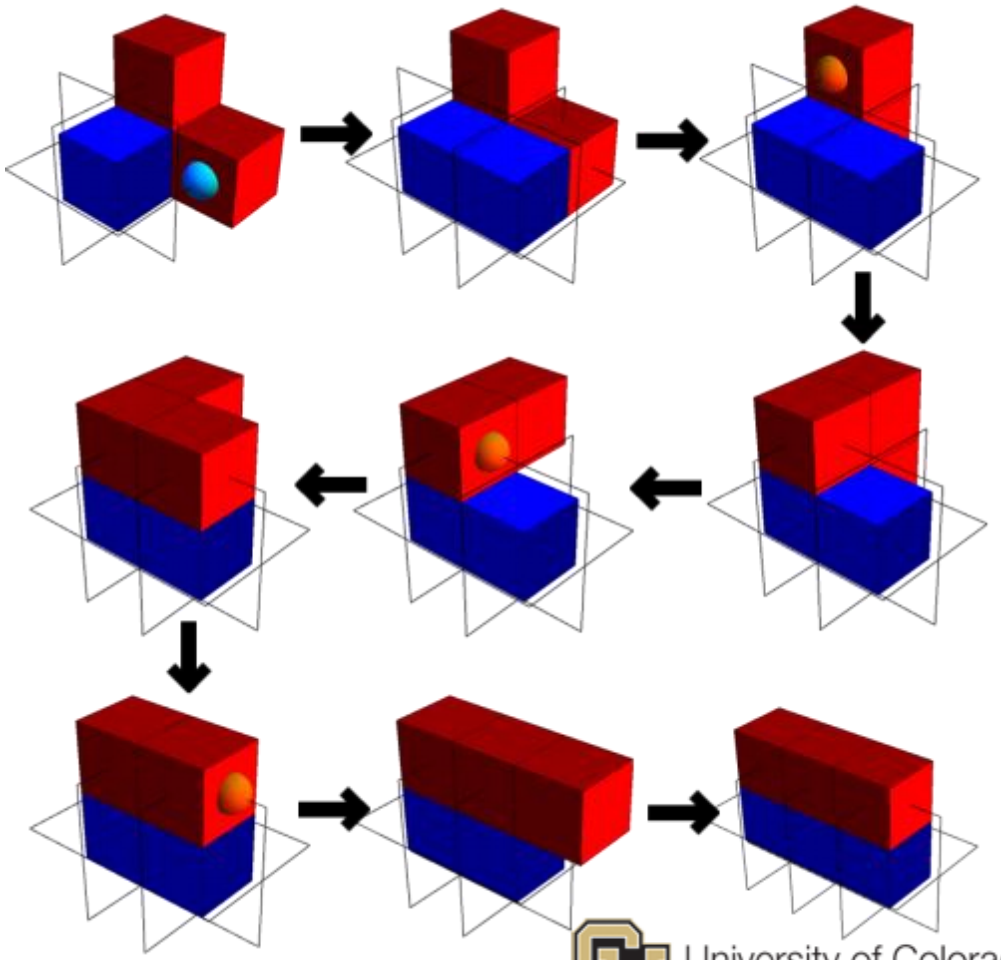
Approach: Intelligent Scaffolds

- Scaffolds (red) coordinate construction
- Three Scaffold blocks can construct any computable structure



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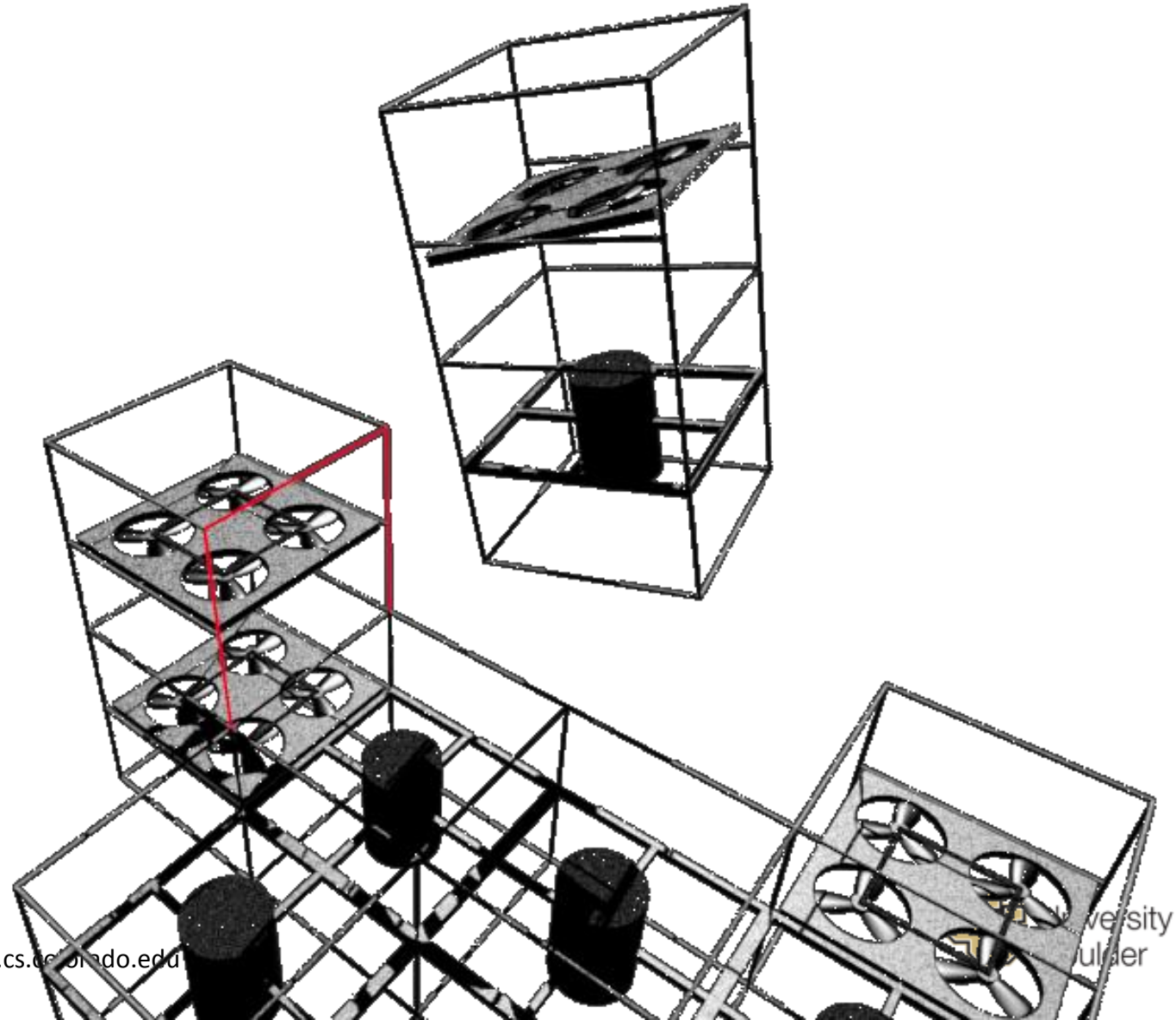
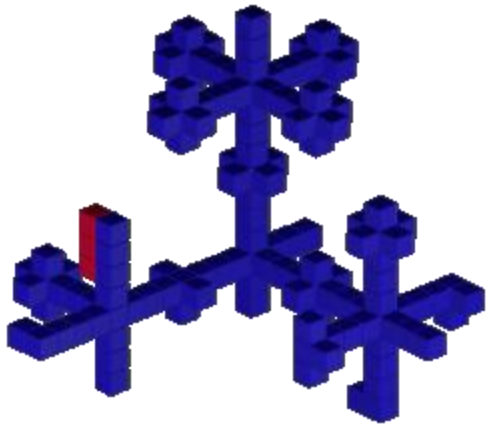
Intelligent Scaffolds



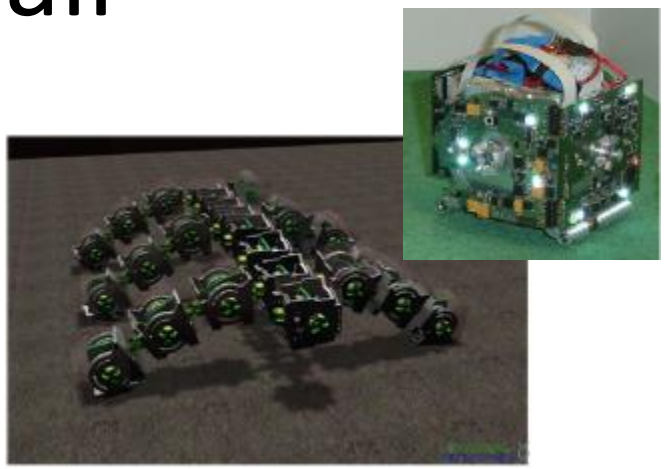
Discussion: Resources

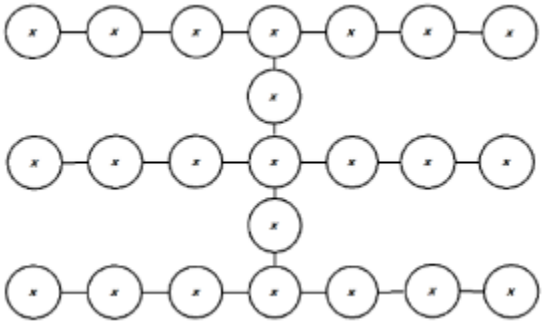
- Intelligent scaffold allow trade-off between number of actuated modules (from 3 to N) and assembly time
- Need new algorithms that use *some* computation & communication in otherwise passive blocks



3. Self-Repair

- Challenge:
  - Detect damage
  - Execute repair
- Approach:
  - Graph grammars
  - Graph rewriting rules



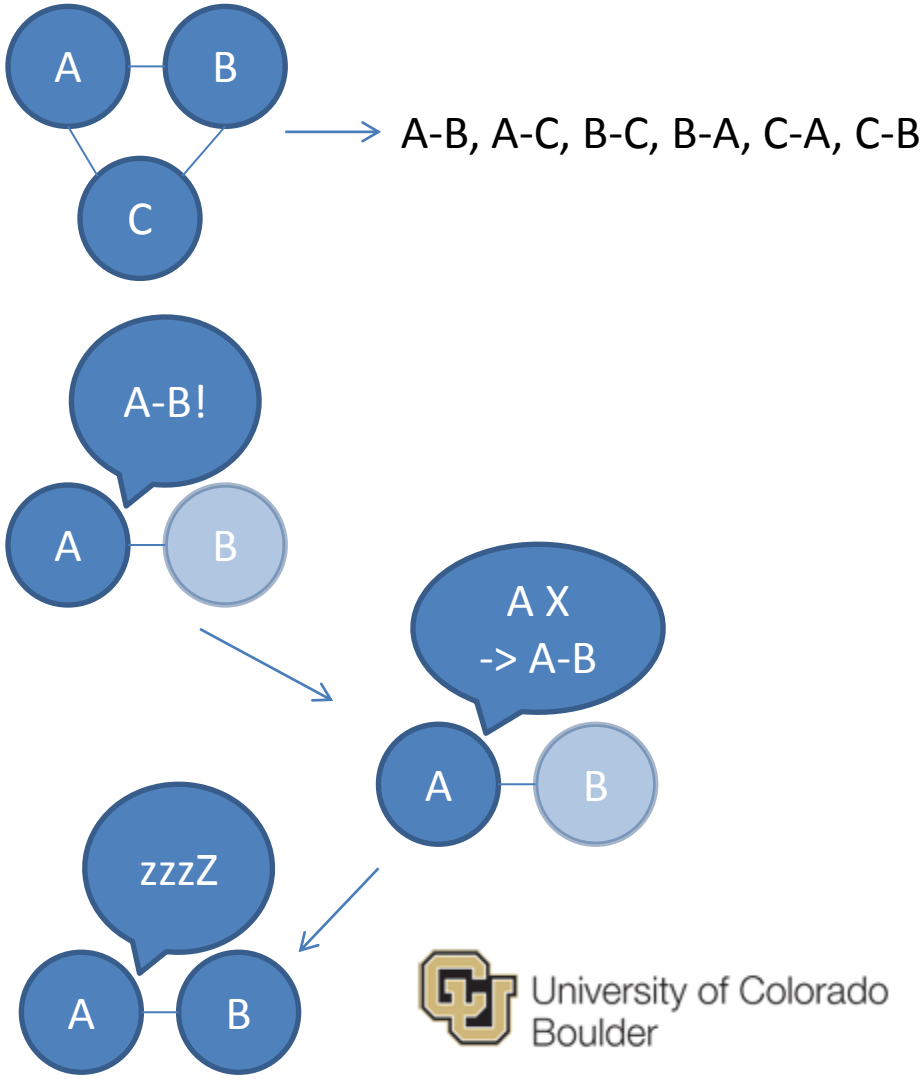


$$\phi_{fi} : X \quad A \Rightarrow Y - Z$$

$$\phi_{ri} : Y - Z \Rightarrow X \quad A$$

3. Self-Repair

- Generate graph grammars to *monitor* and *repair* structural integrity
- Embed monitor and repair rules into material

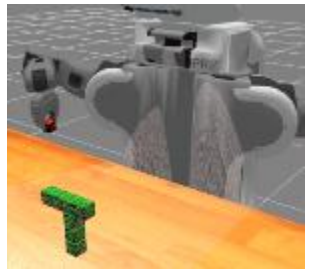


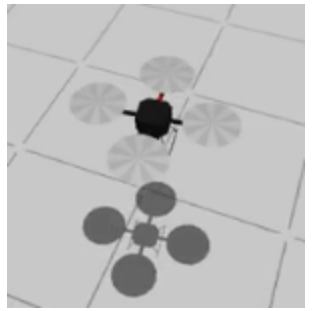
Discussion: Self-Repair

- Requires additional sensing, computation, and communication
- Find right trade-off between
  - Speed of detection/repair
  - Additional resources to embed

Outlook

- From simple physics to (simple) flight dynamics
- Study self-assembly, reconfiguration, and repair in realistic simulation
- Perform preliminary experiments in 2D and 3D





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